SEND COMPLETED DISCLOSURE DIRECT TO:
CORPORATE PATENTS AND LICENSING
Loc. CO, Bldg. C01, M/S A126

INVENTION DISCLOSURE

THIS INVENTION DISCLOSURE IS MADE PURSUANT TO MY / OUR INVENTION AGREEMENT WITH HUGHES AIRCRAFT COMPANY.

HUGHES

1. TITLE OF INVENTION

SHEET 1 OF

Fabrication Technique for Ultra-Low Contact Resistances in GaN-based Devices

2. INVENTOR(S)

NAME	PAYROLL NO.	SOURCE CODE	LOC	BLDG	MS	PHONE	MANAGER
Nguyen Xuan Nguyen	J3259	30-31-20	MA	254	RL61	5551	Jonathan Lynch
Paul Hashimoto	16529	30-31-20	MA	254	RL61	5001	Jonathan Lynch
Nguyen Chanh	J3215	30-30-00	MA	254	RL61	5605	Bill Stanchina

This is to acknowledge that the above Invention Disclosure has been received by Corporate Patents and Licensing. The disclosure will be reviewed at the next Evaluation Committee Meeting of your organization and you will be promptly informed of the results. If you have any questions please contact the patent attorney listed on the bottom of this form.

This sheet will be returned to the inventor(s) as a confirmation of receipt by Corporate Patents and Licensing.

LOSS OF RIGHTS THROUGH RELEASE TO THE PUBLIC

The right to apply for and obtain a valid patent may be lost as the result of certain activities, such as (1) disclosing the invention outside of the company without an appropriate confidentiality agreement with the receiving party; (2) using the invention publicly; (3) using the invention privately to build or test items that are to be sold publicly; or (4) putting the invention "on sale" by selling or offering for sale an item or product that embodies or uses the invention, or is made or tested by use of the invention. Submitting a proposal with the intent to use the invention in the performance of a resulting contract puts the invention "on sale".

Please inform me immediately of any of these activities or any plans to undertake any of them.

ASSIGNED ATTORNEY:

PHONE ( )

LADAS & PARRY
FEB 24 2000
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PATENT DOCKET NO.

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LABORATORIES
DEC 22 1999
PD# 991216

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Paul Hashimoto	16529	30	31	20	MA	254	RL61	317-5001	Jonathan Lynch
Chanh Nguyen	J3215	30	30	00	MA	254	RL61	317-5605	Bill Stanchina

3. PROOF ON CONCEPTION

A. BY WHOM WAS FIRST DESCRIPTION WRITTEN OR DRAWING MADE?	DATE	TIME SPENT	ACCT. CHARGED	LOCATION OF FIRST DESCRIPTION / DRAWING
Nguyen Xuan Nguyen	06/15/99	2 hrs	CD193C6JL	Technical Journal 50017 (MA 254 Rm 4C35)
B. TO WHOM WAS INVENTION FIRST DISCLOSED?	DATE			
David Grider	07/20/99			

4. REDUCTION TO PRACTICE

A. WAS A DEVICE EMBODYING THE INVENTION CONSTRUCTED AND TESTED OR THE PROCESS PRACTICED?	YES X / NO ☐	BY WHOM	DATE STARTED	DATE COMPLETED	TIME SPENT
		Inventors	06/30/99	07/15/99	40 hrs

B. ACCOUNT CHARGED — TIME	ACCOUNT CHARGED — MATERIAL	PRESENT LOCATION OF DEVICE
		HSCL

C. PRESENT LOCATION OF DOCUMENTS (DATE SIGNED AND WITNESSED), INCLUDING PHOTOS, DRAWINGS, AND DATA SHEETS SHOWING REDUCTION TO PRACTICE	MA Bldg. 254 Rm 4C35

NOTE: ALL EVIDENCE OF CONCEPTION (FIRST DRAWING AND FIRST WRITTEN DESCRIPTION) AND EVIDENCE OF REDUCTION TO PRACTICE (DEVICE EMBODYING THE INVENTION AND TEST DATA) MUST BE RETAINED.

5. RELATION TO GOVERNMENT CONTRACT

A. DOES THIS INVENTION RELATED TO WORK PERFORMED UNDER A GOVERNMENT CONTRACT?	YES ☐ / NO X	CONTRACT NUMBER AND TITLE
B. IS INVENTION BEING USED ON A GOVERNMENT CONTRACT?	YES ☐ / NO X	CONTRACT NUMBER AND TITLE

6. RELATED DOCUMENTS AND DISCLOSURE (BY YOU OR BY ANOTHER). PLEASE ATTACH COPY.

		DATE	IDENTIFY
A. IS THERE A PUBLICATION OR PUBLIC PRESENTATION RELATED TO THE INVENTION?	YES ☐ / NO X		
B. ARE THERE ANY RELATED INVENTION DISCLOSURES OR PATENT APPLICATIONS?	YES X / NO ☐	DATE 01/21/97	IDENTIFY PD NO. ETC. PD-960453
C. ARE THERE ANY PROPOSALS OR REPORTS OR OTHER DOCUMENTS RELATING TO THIS INVENTION	YES ☐ / NO X	DATE	IDENTIFY
D. HAS THE INVENTION BEEN USED, DISCUSSED, DEMONSTRATED OR OTHERWISE DISCLOSED OUTSIDE THE COMPANY (SUCH AS TO A VENDOR OR CUSTOMER)?	YES ☐ / NO X	DATE	TO / FOR WHOM (COMPANY / PERSON)

7. SALE

A. HAS PRODUCT EMBODYING INVENTION OR MADE BY INVENTION BEEN PROPOSED, SOLD, OR OFFERED FOR SALE?	YES ☐ / NO X	ORDER NO.	ORDER DATE	DELIVERY DATE	DATE OFFERED OR PROPOSED

Nguyen Xuan Nguyen — SIGNATURE INVENTOR — DATE 12/20/99

Paul Hashimoto — SIGNATURE INVENTOR — DATE 12/21/99

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INVENTION DISCLOSURE

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HUGHES

B. IS PRODUCT EMBODYING INVENTION OR MADE BY INVENTION IN A DELIVERABLE ITEM?	YES ☐ NO X	DELIVERY DATE

Nguyen Linda Nguyen — SIGNATURE/INVENTOR — 12/20/99 DATE

Paul Martinelli — SIGNATURE INVENTOR — 12/21/99 DATE

12/7-12/9

238C-2 CS MAR 95

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PD 991216

8. SUMMARY OF THE INVENTION

SHEET 3 OF _____

A. GIVE A BRIEF DESCRIPTION OF YOUR INVENTION, PARTICULARLY POINTING OUT WHAT IS BELIEVED TO BE NOVEL (THE "HEART" OF WHAT IS NEW).

We disclose a fabrication technique for ultra-low contact resistances in GaN-based FETs. Recent rapid progress in GaN HFET technology provides convincing evidence that it will ultimately have a dramatic impact on a wide range of systems, including future generation radar and satellite communications system. Fundamental to the viability of GaN device technology is its fabrication process; of which the ability to make low and reproducible ohmic contacts to the channel of the device is of imperative importance. The wide band-gap barrier layer, AlGaN, common in GaN-based HFETs renders it impossible to obtain low and reproducible contacts to the underlying channel using conventional alloy contact method. We have developed and optimized a fabrication process that would solve this problem and reduce the contact resistance by an order of magnitude (10X) in GaN HFETs. Thereby, dramatically improve the microwave power and low noise performance of GaN device technology.

We demonstrated the potentials of this fabrication technique via the high performance obtained by the GaN MODFETs fabricated using this technique. The excellent performances obtained on these devices are convincing evidence of the suitability of this technique for obtaining ultra-low contact resistances in GaN-based HFETs.

B. EXPLAIN THE PURPOSE AND ADVANTAGES OF YOUR INVENTION. (WHAT WILL THE INVENTION DO BETTER THAN DONE PREVIOUSLY?)

Conventional alloy contacts in GaN-based HFET usually resulted in contact resistance of 2.0 Ω-mm, which is ten times that of GaAs-based devices. This high contact resistance would lead to very poor DC and RF performance of the devices. We have developed a self-aligned ohmic recess etching technique by reactive ion etching to thin down the wide band-gap barrier layer, AlGaN, thereby enable excellent ohmic contact to the channel of the devices. Systematically optimizing this technique enable us to obtain contact resistance as low as 0.2 Ω-mm for GaN-based HFET. This is the lowest contact resistance reported for this material system.

SIGNATURE INVENTOR		DATE 12/20/99
SIGNATURE INVENTOR		DATE 12/21/99
READ AND UNDERSTOOD BY:		DATE 12/20/99
WITNESS NAME (TYPE) MEIYIN MATLOUBIAN	SIGNATURE	DATE 12/20/99
WITNESS NAME (TYPE) Jonathan Lynch	SIGNATURE	DATE 12/21/99

236C-3 CS MAR 95 (EACH PAGE UPON WHICH INFORMATION IS ENTERED SHOULD BE SIGNED AND WITNESSED)

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PD# 991216

8. SUMMARY OF THE INVENTION *(Continued)* SHEET 4 OF _____

C. IDENTIFY THE COMPANY PROGRAM OR PRODUCT LINE TO WHICH THE INVENTION APPLIES, AND THE EXPECTED VALUE TO THE PROGRAM OR PRODUCT LINE. ALSO IDENTIFY POTENTIAL COMMERCIAL APPLICATION OF THIS INVENTION, INCLUDING AUTOMOTIVE APPLICATIONS, IF ANY.

This invention applies to all programs and product lines related to microwave power and low-noise amplifiers. The following programs are particularly benefited by this invention:

- Active array radars at X-band: >$100M
- Power amplifiers for Wireless Satellite/Communications applications: >$200M

We are currently funded for these programs by Raytheon System Company

D. IDENTIFY THE PRIOR ART KNOWN TO YOU WHICH IS IMPROVED UPON OR DISPLACED BY YOUR INVENTION, AND STATE IN DETAIL, IF KNOWN, THE DISADVANTAGES OF THE CLOSEST PRIOR ART.

The common approach in compound semiconductor to obtain good ohmic contacts is to alloy the metal contacts above a certain temperature. This approach works very well for GaAs and InP-based materials and devices. However, for GaN-based materials, this approach would yield unacceptable high contact resistances. The fundamental problem is the wide band-gap barrier layer, AlGaN, in GaN-based HFET structures. The AlGaN barrier layer inhibits the ohmic metals from diffusing into the channel and form proper contacts. In order to mitigate this diffusion limitation and facilitate good ohmic contact to the channel of the device, we have systematically thin down the barrier by reactive ion etching the AlGaN barrier away.

SIGNATURE INVENTOR 12/20/99 DATE

SIGNATURE INVENTOR 12-21-99 DATE

READ AND UNDERSTOOD BY: 12/20/99 DATE

WITNESS NAME *(TYPE)* SIGNATURE 12/20/99 DATE

WITNESS NAME *(TYPE)* SIGNATURE 12/21/99 DATE

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9. DETAILED DESCRIPTION SHEET 5 OF _____

DESCRIBE YOUR INVENTION IN DETAIL, USING NECESSARY ADDITIONAL SHEETS

A. BE SURE THAT EACH SHEET IS DATED, AND SIGNED BY EACH INVENTOR AND TWO WITNESSES. (HAC FORM 236C-6 CS SHOULD BE USED, IF PRACTICAL).

B. ATTACH COPIES OF DRAWINGS OR DETAILED REPORTS HELPFUL IN UNDERSTANDING HOW YOUR INVENTION WORKS

C. IF YOUR INVENTION HAS BEEN TESTED, BRIEFLY SUMMARIZED THE TEST RESULTS WHICH CONFIRM THE FUNCTIONS AND ADVANTAGES LISTED IN 8 B ABOVE.

The self-aligned ohmic recess etching was done prior to ohmic metallization. The detailed ohmic metallization scheme for GaN-based HFETs is listed below:

1. Ohmic pattern definition by photolithography
2. Ohmic recess etching using Chlorine-RIE with the following conditions -
   - DC bias – 100V
   - Chamber pressure – 5 mT
   - Cl_2 Flow rate – 10 sccm
3. Metallization with Ti/Al/Ni/Au metals
4. Contacts alloying at 875°C

The etch-rate of the Chorine (Cl_2) RIE was systematically characterized, and shown in Figure 1. Based on this etch-rate, we have optimized the ohmic recess scheme and achieved contact resistance of 0.2 Ω-mm (figure 2). This contact resistance is the state-of-the-art for this material system.

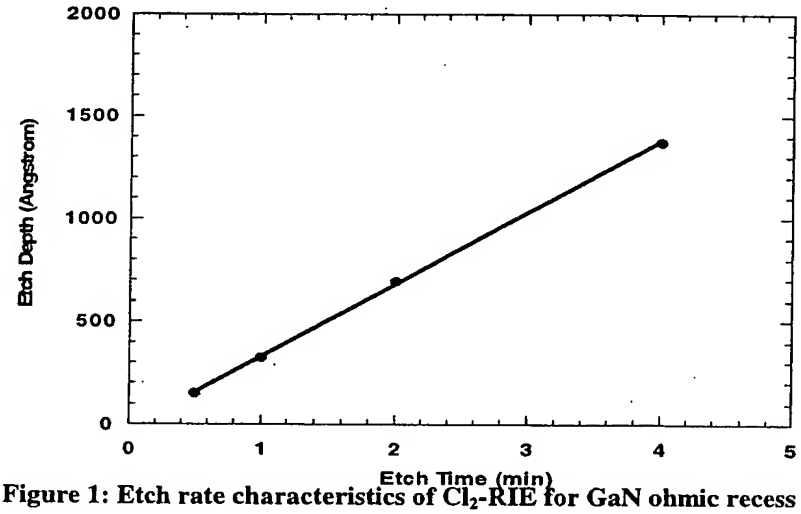

Figure 1: Etch rate characteristics of Cl_2-RIE for GaN ohmic recess etching.

SIGNATURE INVENTOR 12/20/99 DATE

SIGNATURE INVENTOR 12-21-99 DATE

READ AND UNDERSTOOD BY: 12/20/99 DATE

WITNESS NAME (TYPE) SIGNATURE

WITNESS NAME (TYPE) SIGNATURE 12/21/99 DATE

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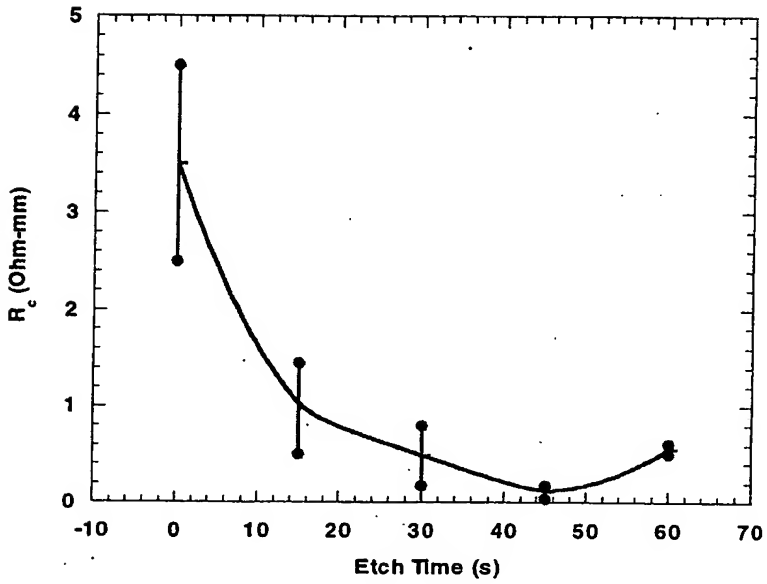

Figure 2 – Contact resistance as a function of etch-time (i. e. etched thickness); a 15X improvement in contact resistance is obtained.

Regina Ursaw Ramos — SIGNATURE INVENTOR — 12/20/99 DATE

Paul Mastrocola — SIGNATURE INVENTOR — 12-21-99 DATE

READ AND UNDERSTOOD BY: — 12/20/99

Richard Lethal — WITNESS NAME (TYPE) — SIGNATURE — 12/20/99 DATE

Mark Thompson — WITNESS NAME (TYPE) — SIGNATURE — 12/21/99 DATE

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